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PB-258 712-T

Cyclone-Electrothermal Methods of Processing Copper and Polymetallic Materials

Environmental Protection Agency, Research Triangle Park, N C

1968

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PB 258 712-T
EPA-TR.436-B-73

CYCLONE-ELECTROTHERMAL METHODS OF PROCESSING COPPER AND POLYMETALLIC MATERIALS

[Tsiklonno-elektrotermicheskiye sposoby pererabotki mednogo i polimetallicheskogo syr'ya]

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Izdatelstvo "Nauka" Kazakhskoy SSR, Alma-Ata
1968, pp. 1-61

Translated for EPA by
SCITRAN (SCIENTIFIC TRANSLATION SERVICE)
SANTA BARBARA, CALIFORNIA

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SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA TR73-436B	2.	3. Recipient's Accession No. PB-258 712-T
4. Title and Subtitle: Cyclone- electrothermal methods of processing copper and polymetallic materials- special features of the work of cyclone chambers with an upper outlet for gases			5. Report Date 1968 6.
7. Author(s) A.V. Tonkonogiy, E. Balfanbayev, et.al.			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: TRANSLATED FROM RUSSIAN BY EPA			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address: Translation Service, Office of Administration - Library, Research Triangle Park, NC 27711			13. Type of Report & Period Covered 14.

15. Supplementary Notes

Izdatelstvo "Nauka" Kazakhskoy SSR, Alma-Ata 1968.

16. Abstracts

17. Key Words and Document Analysis. 17a. Descriptors

EPAISD

17b. Identifiers/Open-Ended Terms

NON - RENEWABLE RESOURCES

17c. COSATI Field/Group 11F 71N

PRICES SUBJECT TO CHANGE

18. Availability Statement: TRANSLATED FROM NON_COPYRIGHTED TEXT	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 36
	20. Security Class (This Page) UNCLASSIFIED	22. Price 4.00/300

USCOMM-DC 40329-P71

This volume contains articles summarizing the results of investigations of processing the copper and polymetallic concentrates and other products of nonferrous metallurgy by the cyclone method. The results of theoretical studies of the technology of cyclone smelting of sulfide concentrates are also included. Certain structural features of a cyclone facility for direct-flow and separated outflow of the smelting products and of gas are described. Also, technological characteristics are given for smelting of copper concentrates of Central Kazakhstan, industrial concentration products of the lead-zinc ores, and oxidized materials.

The material in this volume will be of interest to scientists, workers in metallurgical plants who investigate methods of processing sulfide concentrates in pulverized form, and to instructors and students in the institutions of higher learning.

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SPECIAL FEATURES OF THE WORK OF CYCLONE CHAMBERS WITH AN UPPER OUTLET FOR GASES

A. V. Tonkonogiy, E. Balfanbayev, V. V. Vyshenskiy
and P. V. Kopytkov

At the present time the cyclone principle is utilized successfully in many technological processes of industry. Naturally, for each specific type of raw material, questions have to be answered regarding both the working parameters of the process, and the constructional set-up of the assembly.

In processes of pyroselection and a number of others which do not require settling of the melt, one of the basic ways of improving the facility and obtaining better technological indicators is the application of cyclone chambers with separate outlets for gases (upwards) and for the melt (downwards). Such a chamber separates liquid and gaseous phases directly in the melting space, and eliminates from the assembly an expensive unit — the settling reservoir for the melt. The coupling of the melting facility with units following it whose surfaces utilize the heat from the chamber is simplified. The application of cyclone chambers of such a construction prevents the occurrence of reverse reactions between the liquid and gaseous phase, and considerably increases one of the basic indices of the pyroselection process — the enrichment of sublimates with precious elements, as a consequence of an increase of the slag recovery coefficient. KazNIIenergetiki has studied the aerodynamics, the burning of liquid and solid fuels, and smelting of ores in various cyclone chambers with an upper outlet for gases.

The aim of the investigations was to develop the construction of a chamber, which would most fully satisfy the basic requirements placed on power engineering units. Attempts were made to obtain the highest heat evolution and temperature from the gas medium necessary for the technological process, in a minimal volume of the chamber and at its maximum separation capacity.

Cyclone Chamber of Cylindrical Form

Aerodynamic Studies of Isothermal Current. Models of the cyclone chamber (Figure 1a) with an upper outlet for gases were used to conduct measurements of the tangential and axial components of the velocity vector and measurements of static pressure. Eighteen various constructional variants were tried out. We shall not deal here in detail with the dependence of the velocity components and static pressure on construction parameters, since we considered this matter earlier [1]. We shall analyze only their effect on the structure of the current and on the subsequent processes — inflammation, burning of the fuel, and thermal processing of the material.

The successful inflammation (ignition) and burning of the fuel is determined, to a large degree, by the construction of assembly, as was shown convincingly in the works of G. F. Knorre [2], Yu. L. Marshak [3] and also of foreign investigators [4]. First of all, it is necessary to ensure that there is recirculation of hot gases to the base of the flame, since it is the basic thermal factor for maintaining a steady flame.

In this connection, it is of special interest to determine the fields of axial velocity in the chamber, namely, the reverse ring current and the outlet vortex, depending on changes of the basic constructional parameters: the relative area of the air inlet (with respect to the cross section area of the cyclone) — F_{in}/F_c, the relative length of the furnace vent (with respect to the height of the cyclone chamber) — l_v/D_c, and the diameter of the vent (with respect to the diameter of the chamber)— d_v/D_c.

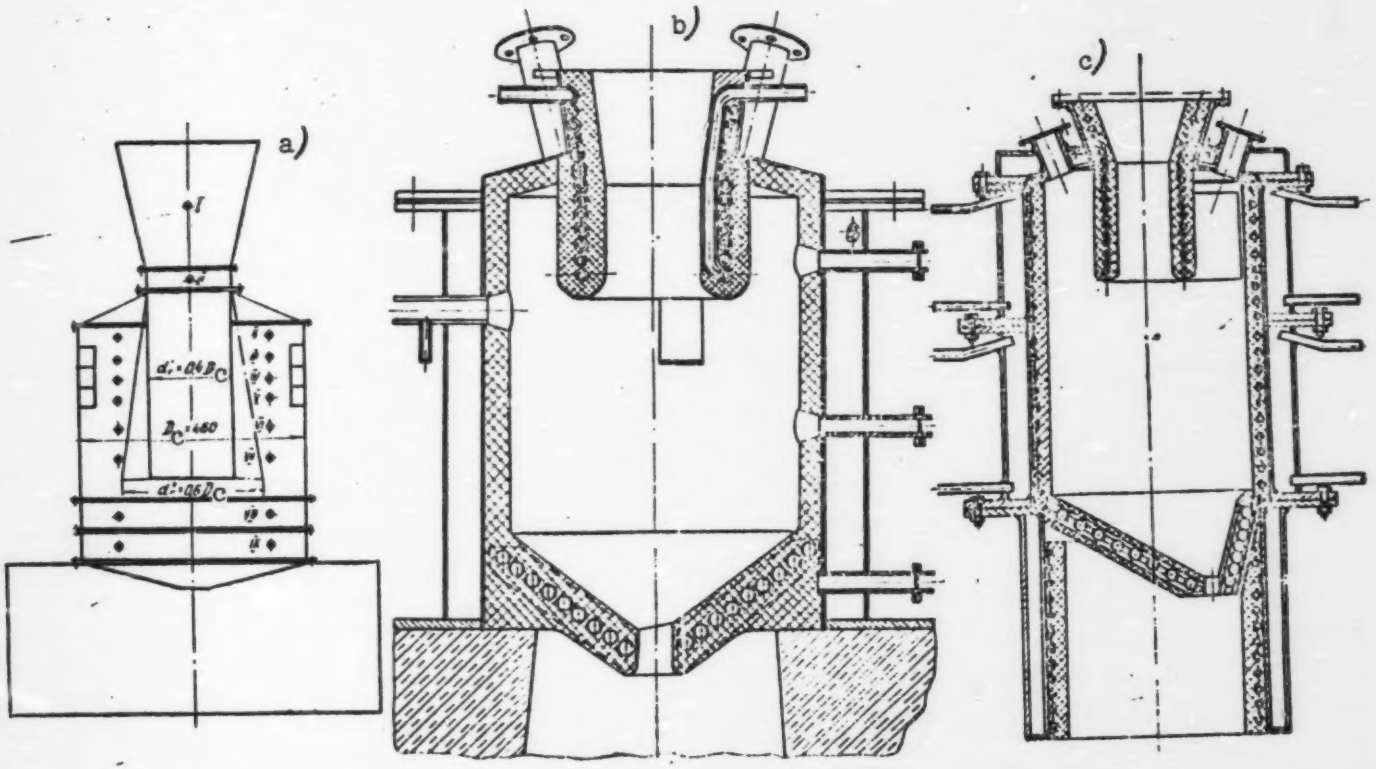

Figure 1. The cyclone chamber with an upper outlet for gases:

a — isothermal model; b — the first variant of the cyclone chamber; c — the second variant of the cyclone chamber.

An increase of F_{in}/F_c leads to a general increase of axial velocities in the cyclone chamber — the reverse ring and axial current, and the outlet and descent vortices. However, the air inlet area is determined by the forcing of the cyclone chambers and by the given velocity of entering air.

For each chamber and a given type of ore, the parameter F_{in}/F_c is practically constant and it is not possible to utilize its effect on aerodynamics. It must be only considered that, for the full development of the aerodynamics of cyclone, it is desirable to have the largest area of the inlet, which corresponds to the maximum possible forcing of the chamber. This is confirmed by the practical operation of cyclones: the most intense thermal processes are observed only for the forced regime.

A decrease of the constriction d_v/D_c leads to an increase of axial velocities in the area of the outlet vortex (with simultaneous increase of the total velocity vector). This may lead to capture in the firing chamber by the outgoing jet of the drops of melt dripping down into the vent, and to removal of these drops from the cyclone chamber through the vent. On the other hand, a decrease in the constriction results in an increase of the rotating zone ("stagnant" in the axial direction) in the middle part of the cyclone chamber, where the total velocity vector lies in the plane of the transverse cross section of the chamber. An increase of the "stagnant" area should prove to be beneficial for calcination and smelting of the solid chunks of material, since they are drawn by the transverse motion of the stream during rotation, and their time of residence within the chamber is increased. Consequently, a decrease of the constriction results in an improvement of the conditions of burning and melting particles within the chamber and their separation on the wall.

Consideration of the effect of constriction on the axial velocities leads to two contradictory requirements with respect to the diameter of the outlet vent. In this connection, we proposed and tested on firing facilities a vent of variable cross section, satisfying both

requirements mentioned, and eliminating the contradiction [5]. A broadened "stagnant" area forms in the upper part of the cyclone, and the minimal velocity of the outgoing stream is ensured at the vent opening.

The effect of the vent length is primarily apparent in the formation and spreading of the reverse ring current. A decrease of l_v/H_c from 0.7 to 0 (chambers without vents) results in a continuous increase of the absolute value of the reverse ring current and the depth of its penetration from the bottom of the chamber to its lid. But when the vent is long, the reverse ring current becomes localized only near it and does not spread into the annular zone. Conditions for fuel combustion in the upper part of the cyclone should become worse, as confirmed in tests of the chamber during burning of coals.

Burning of coals. The experiments on burning of solid fuels utilized the Lengersk coal type "B." The fineness of grinding this coal varied in rather a broad range: R_{200} = 6.67 — 2.3%, and R_{79} = 49.9 — 63.8%.

The tests were carried out on two cyclone chambers (Figures 1b, 1c) of different diameter. The throughput of coal dust varied from 200 to 515 kg/hour, the input velocity of secondary air — from 100 to 170 m/sec, and the input velocity of the air mixture — from 15 to 30 m/sec. The air temperature in various experiments varied from 300 to 585° C. The experiments confirmed our original conclusions, based on aerodynamic investigations of cold models.

In a facility with a short output vent (l_v/H_c = 0.5) in the upper part of the chamber (Figure 1b), the combustion process develops successfully. However, the lower part is not filled satisfactorily with the flame, and this flame leaves the chamber through the vent without reaching the bottom of the cyclone. As a result, the temperature level in the lower part of the chamber is insufficient for maintaining the liquid-flowing state of the slag. For the same reason, a small amount of gases pass through the tapping hole. The combination

of these factors leads to solidification of the slag and to sealing off of the tapping hole. And if we initially increase its diameter, we lose one of the advantages of the cyclone chamber — a separate outflow of gases and of the melt.

An increase of the vent length displaces the combustion of the fuel-air mixture into the lower part of the chamber, thus ensuring sufficient liquidity of the slag. In this case, however, the combustion in the upper part of the chamber deteriorates, and the zone of stable fuel combustion becomes displaced to the vent opening. Nearly two-thirds of the height of the annular space, formed by the vent and the outside wall of the chamber, lies at a low temperature (less than 1000° C).

It is necessary to note that one of the cyclone variants had a conical bottom part with a large inclination angle and an asymmetrically placed tapping hole. This variant, however, was completely unsuitable, since it led to a considerable loss of unburnt chunks of coke through the tapping hole. As shown by special investigations, this behavior is explained by the fact that, with a conical bottom, the conditions for formation of a reverse ring current deteriorate, down to its complete degeneration. And the presence of reverse currents ensures circulation of unburnt particles of the fuel, so that eventually they undergo combustion. According to our view, a conical bottom may be useful (from the viewpoint of the removal of melt) but on condition that the total process of the fuel combustion takes place in the upper or middle part of the chamber; but in cyclone chambers of this type, the bottom should be of the flat form.

The width of the annular gap between the vent and the external wall of the investigated chamber was 130 mm. To check the effect of the width of annular gap on the ignition of the air-fuel mixture at its place of introduction, we constructed and tested a cyclone chamber of diameter 710 mm and the width of annular gap equal to 200 mm (Figure 1c). However, the combustion in the upper part of the chamber showed no change. We did not succeed either in improving conditions of ignition and burning in the upper part of the chamber having a long

vent ($l/H_c > 0.5$) when we raised the temperature of preheating the air to 550 — 580° C, when we increased the velocity of secondary air to 170 m/sec, or when we lowered the velocity of introduction of the air-fuel mixture from 30 to 15 m/sec.

Thus, the results of investigations have shown that the tested designs of cylindrical chambers do not satisfy the above-discussed requirements pertaining to power engineering assemblies. Apparently, the arguments apply with respect to chambers of relatively small dimensions ($D_c < 2$ mm). But we need to use chambers of large diameters for power engineering purposes, particularly for the pyroselection of precious metals, considering their low separational capability. In this connection, we proposed and developed a chamber of a new construction, with an annular stabilizing channel.

The Cyclone Chamber with Annular Stabilizing Channel

The cyclone chamber developed at KazNIIenergetiki [6] has the upper cylindrical part broadened and forming an annular stabilizing channel at the entrance of fuel and air. Such a chamber ensures the return of hot gases to the base of the flame down to the bottom of the channel, and sharply increases recirculation of gases in the upper part of the cyclone. Moreover, when such a channel has a radius of curvature close to the value of its width, then, as is known, a transverse circulation of the gas stream occurs. As a result, particles of the fuel and of the processed material should be dragged by the stream in a double circulatory motion, and the time of their residence within the channel increases fast. All these phenomena considerably intensify the process of combustion and thermal treatment of the ore.

Aerodynamic investigations. A schematic sketch of the cyclone chamber model which was used for conducting the investigation is shown in Figure 2a. In contrast to the profile of tangential velocities characteristic of conventional cyclone chambers, the stabilizing channel shows no clearly-defined turns and drops, and the profile is practically constant along the width and height of the channel and

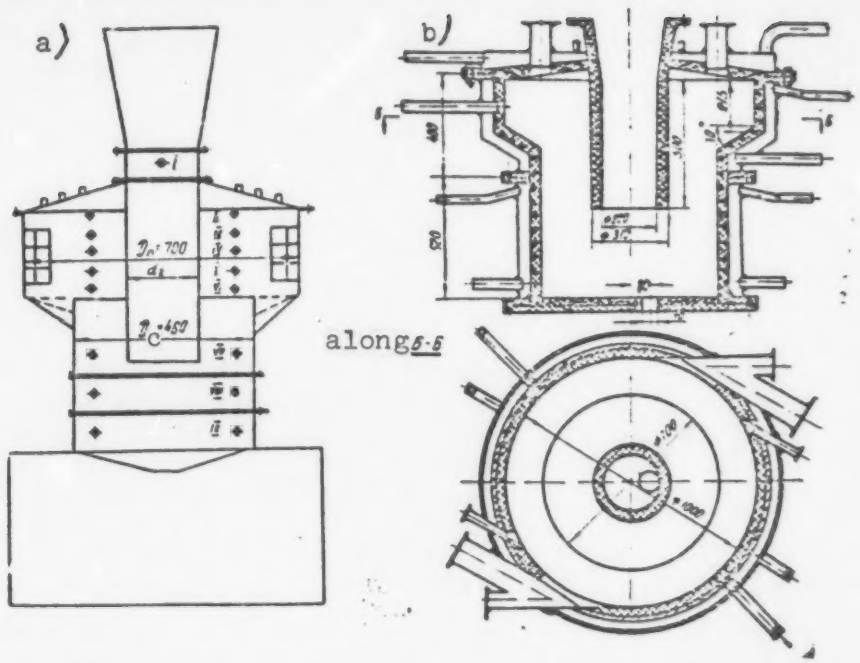

Figure 2. The cyclone chamber with a stabilizing annular channel.
a — isothermal model; b — semi-industrial firing chamber.

along all cross sections and radii (Figure 3a). At $F_{in}F_c$ equal to 0.018, the average integral value of the tangential velocity v_c/c_{in} is 0.65 — 0.7, and at F_{in}/F_c = 0.036 this value increases to 0.9.

The distribution of axial velocity in the annular channel changes along its length. The entering stream in the area adjacent to the wall is directed downwards for the distance from the inlet slits to 1/4 the length of the circumference. Then, in the course of its further advance, the stream gradually deviates from the loading platform (Figure 3b) and, on completion of the whole turn, it becomes directed to the inlet slits and moves entirely towards the lid of the cyclone. At the same time, there is a strong descending gas current along the whole height of the channel and over all of it. This current has the maximum velocity at a radius corresponding to the radius of the lower part of the cyclone. Of particular interest is the distribution of radial velocity (Figures 3c, 3d), which continuously increases at the

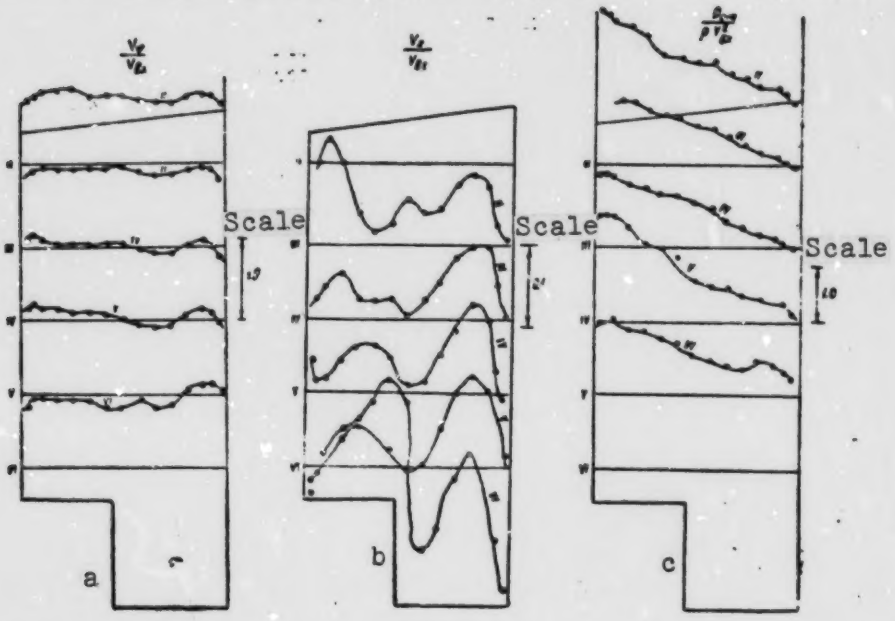

Figure 3. Distribution of the velocity components in the stabilizing annular channel.

approach to the loading platform of the channel and also in the direction of the cyclone axis. The increase of the radial velocity component can be explained by the fact that the current loses its peripheral velocity near the horizontal planes. Flow arises in the direction opposite to the pressure gradient, at such a velocity that it causes the appearance of friction forces which compensate for decrease of the centrifugal forces.

Joint inspection of axial and radial velocities indicates the presence of two complementary transverse vortices, typical for the picture of secondary circulation in curvilinear channels.

Burning of coals. Coals of Lengersk origin, and also lignites of Bakhtinsk and Symsk deposits were burned in the cyclone chamber with a stabilizing channel (Figure 2b). The temperature characteristics of cinders of the Bakhtinsk lignites were: t_1 = 1180°, t_2 = 1230°, t_3 = 1430° C. The cinders of Symsk lignites were easier to melt (t_3 = 1290° C), but their ash content amounted to only 4 — 7%, which

corresponds to the lower limit required for steady work of the cyclone chamber with the formation of slag lining.

To make the experimental conditions closer to conditions of industrial facilities, the preheating temperature of secondary air was kept within 380 — 450° C. The apparent thermal intensity of the cyclone varied in the experiments within $BQ/v = (6 — 11)\cdot 10^6$ kcal/m^3 •hour. The velocity of secondary air was 125 — 170 m/sec, and the velocity of supplying of the air-fuel mixture was kept at 13 — 28 m/sec. The operation of the chamber was investigated both for one-sided and two-sided introduction of air and fuel.

The investigations [7] have shown that the cyclone chamber of this construction implements steady ignition and burning of the air-fuel mixture directly at the inlet. This feature is explained by both the longitudinal and transverse circulation of hot gases, returned to the base of the flame.

Two zones stabilizing the combustion are distinctly apparent in the cyclone. The first one refers to the lower section of the annular channel, where intense radial currents of gases appear. These currents, directed to the cyclone axis, mix and contract the main current. The second zone appears at the vent opening, where burning of fuel takes place.

A high temperature (1600 — 1800° C) develops in the upper part of the chamber, ensuring effective thermal treatment of the material. The combustion process is fully completed in the chamber at rather low coefficients of air excess $\alpha = 1.05 — 1.1$. There are no losses due to chemical incomplete combustion, and the carbon content in the slag does not exceed 0.2 — 0.4%.

The operation of the chamber is characterized by a high coefficient of slag recovery — up to 94 — 95%, for an ash content of coals above 15%. When the ash content is reduced to 4 — 7 % (during combustion of Symsk lignites), the coefficient of slag recovery falls to 75%. This can be explained by the instability of the slag film on the chamber surface.

The strength of the cyclone chamber with these constructional features is approximately 10% higher than that in chambers of cylindrical form.

The high intensity of thermal processes achieved in the cyclone chamber with stabilizing annular channels made it possible to process in this chamber various types of technological raw materials.

Technological investigations. A series of preliminary experiments was carried out on smelting cinders of coals from the Podmoskovnyy Basin and granulated slag from the Leninogorsk lead works. These materials differ sharply with respect to the temperature characteristics, granulometric composition, and specific weight. The Podmoskovnyy cinders were characterized by a high melting temperature (t_1 = 1300°, t_2 = 1450°, t_3 = 1560° C) — which is 100 — 130° C higher than the limits usually recommended for cyclone furnaces, by a fine dispersion (particles less than 56 microns — more than 70%), and also by a low bulk density (γ = 0.7 ton/m^3). The Leninogorsk slags, on the other hand, were distinguished by a low melting temperature ($t_3 \leq$ 1250° C), a coarse fractional composition (particles above 1 mm — about 40%), and also a high bulk density (γ = 2.3 ton/m^3).

The investigated variables included the tangential and axial loading of material, and the supply of liquid fuel through mechanical atomization sprayers either in separate connecting pipes located along the slits for secondary air, or directly into the stream of secondary air.

It is necessary to note that processing of an inert technological material, such as coal cinders and slags, creates difficulties in organization of the thermal process in cyclone chambers. Introduction of such a material into the cyclone is equivalent to the actual increase of the fuel ash fraction. Indeed, during the combustion of coals even with the highest ash content (40 — 50%), for each 1000 kcal of heat liberated in the furnace there is no more than 0.1 — 0.125 kg of ash. But in technological cyclone chambers, for each 1000 kcal of heat we have 0.25 — 0.3 kg of ballast, i.e., two or three times more than in a power furnace.

This circumstance, more than anything else, necessitates such an organization of the process in the chamber that the burning of fuel takes place in a shorter inlet section, and the technological raw material enters a zone of already fully developed burning flame.

During the processing of these materials in the chamber, successful performance of the technological process was done with the axial introduction of material through points located on the roof of the chamber and displaced by 180° from the air entrance, and with the addition of fuel through the mechanical atomization sprayers directly into the secondary air. The productivity of cyclone chambers with both types of fuel reached 800 — 850 kg/hour, which corresponds to specific productivity of 2.5 ton/m^3 hour, with a liquid fuel expenditure of 220 — 250 kg/hour.

The experiments performed enabled us to design a new construction of the chamber on a semi-industrial scale, and gave us an opportunity to initiate longer studies.* We processed more than 35 tons of material, prepared directly at the plant, and containing 8 — 24% carbon.

The basic technological goal was to enrich the sublimates with volatile precious metals which were contained in the charge.

The chemical composition of the mineral part of the charge was: SO_2 = 36.0%; Fe_2O_3 = 8.0%; Al_2O_3 = 19.0%; CaO = 23.0%; MgO = 3.4%; ZnO = 1.5%; Pb_2O = 0.1%; SO_3 - 7.0%. The temperature characteristics were: t_1 = 1140° C; t_2 = 1190° C; t_3 = 1300° C.

The experiments were carried out in a cyclone chamber (Figure 4) with one-sided inlet of air and liquid fuel, and axial loading of the charge. We changed the configuration of the bottom part of the cyclone, the location and diameter of the tapping hole, and also the configuration of the outlet vent. Altogether, we performed 11 experiments in a broad range of chamber productivity per load — from 240 to 820 kg/hour; expenditure of liquid fuel — from 126 to 265 kg/hour; and inlet

*The work was performed together with Giredmet and AKhMZ.

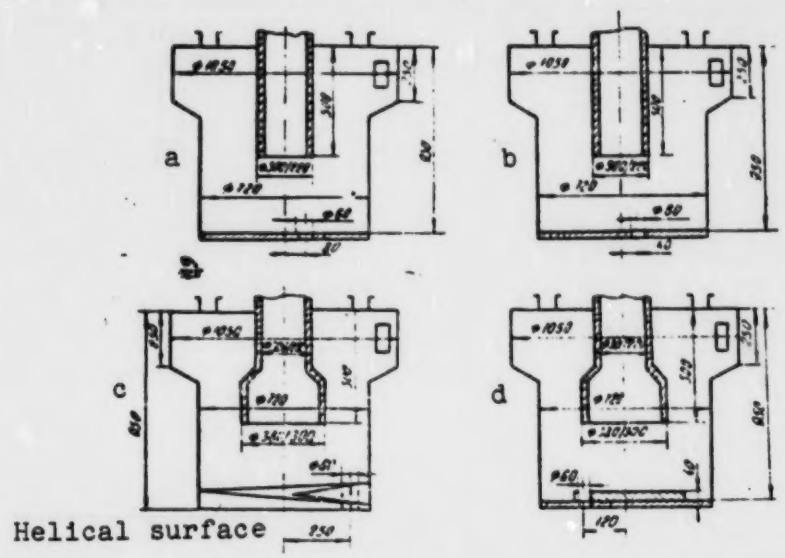

Figure 4. Investigated variants of power engineering cyclone chambers.

velocity of the secondary air — from 107 to 182 m/sec, with the secondary air preheated to 380 — 440° C. The recovery of sublimates from smoky gases was done on sleeve filters. A steady course of the process was achieved in a cyclone chamber with stabilizing annular channel [7]. The annular channel was the site of intense burning of fuel and attainment of a high temperature, which predetermined the effective thermal processing of the material virtually throughout the entire chamber. The smelting of the charge proceeded steadily under all conditions, but in a number of cases there was loss of melt through the vent into the gas line. This loss was minimal in the variant with a broadened output vent and a step-like bottom part (Figure 4); there was no loss altogether when the exit velocity of gases was 80 m/sec. In all the experiments, the walls of the chamber, including the stabilizing channel, were covered with a thin and even layer of hardened slag lining without incrustation and blisters.

The average enrichment multiplicity factor of sublimates with metals, in comparison with the load charge, was 31.5 with the losses of melt being about 15%. At the same time, the enrichment multiplicity factor on a stand cyclone chamber of KazNIIenergetiki

with a lower outlet for gases amounted to 7 — 9 for the same recovery of metal. An analogous enrichment was achieved in industrial cyclone chambers with a lower outlet for gases (with somewhat larger losses of metal with the melt — up to 20 — 25%).

The high technological indices of smelting obtained have confirmed that this cyclone chamber was a considerable improvement over the existing chambers. The chamber was recommended for use in industry, and one plant facility is already being built.

Special investigations of the combustion of liquid fuel. It was noticed during an examination of a chamber operating on liquid fuel that the fuel spraying fineness had a pronounced influence on the intensity of the technological process. This fact served as a basis for special studies on burning of liquid fuel in the chamber to find the optimal operational conditions, ensuring the maximum intensity of the thermal process directly in the upper part of the cyclone. Of particular interest was burning of the fuel jet (flame) in the stabilizing annular channel. The cyclone chamber (Figure 4) was equipped with apertures and sleeves for insertion of water-cooled gas sampling tubes and thermocouples. The apertures were placed in 4 rows along the top of the chamber and in groups of 4 along the generatrix of the cylinder. About 30 experiments were carried out; they differed with respect to the expenditure of fuel, the diameter and number of sprayers, and also their locations, the coefficients of the air excess, the velocity and temperature of secondary air, and a number of other parameters.

Samples of gases for the analysis were withdrawn in the annular channel in the plane R_2, forming an angle of 120° with the location of fuel introduction, and in the plane R_4 at 300° from the location of fuel introduction. The analysis of gases for combustible components was done on a chromatograph GSTL. The total coefficient of the air excess was kept constant $\alpha = 1.065 \pm 0.005$ and was controlled by the expenditure of fuel and the amount of air supplied, as well as by the gas analysis directly at the outlet from the cyclone chamber. The sprayers used were of the centrifugal type, with differing diameters

(3.0, 1.0, 0.7 mm), placed directly into the stream of secondary air, with fuel dispersion along the current and against it. The fuel pressure was maintained in the range 2-6 kg/cm^2.

The preliminary evaluation of the quality of dispersion of liquid fuel [8], using sprayers 3 mm in diameter, has shown that the change of the throughput of fuel from 150 to 320 kg/hour leads to a decrease of the median diameter of the drop from d_M = 320 μ to d_M = 250 μ; correspondingly, the maximum dimension of the drops decreases from D_{max} = 540 μ to d_{max} = 450 μ). In the case of sprayers 0.7 mm in diameter, the effect of the throughput of fuel is less pronounced, and the average diameter of the drops remains d_M = 40-70 μ.

We shall consider the effect of basic factors on fuel combustion in the chamber.

The effect of the diameter of sprayers. With a decrease of the diameter of sprayer nozzle, and a corresponding decrease of the size of droplets, we have a sharp decrease of the chemical incomplete combustion q_{XH}. For instance, in the case of fuel dispersion in the stream along the plane R_2, a decrease of the sprayer diameter from D_s = 3 to 0.7 mm, all other conditions remaining equal, results in a decrease of the maximum value of q_{XH} from 56 to 9% (Figure 5 a), and in an increase of the extent (completeness) of the evolution of heat from 44 to 91%. The coefficient of air excess α, with a sprayer diameter of 3 mm, is distributed in a very nonuniform manner and changes from 1.65 to 0.75 along the depth of the channel. When the sprayer diameter is 0.7 mm, the value of α remains practically unchanged along the radius and is equal to 1.0-1.07. An analogous picture (Figure 5 b) is also observed in the plane R_4, where the chemically incomplete combustion also decreases by a factor of 5-5.5 as the sprayer diameter is made smaller. If, however, D_s = 3 mm, the nonuniformity of concentration fields becomes even larger and the value of α changes from 2.0 to 0.9 along the depth of the channel. An analogous dependence of the effect of sprayer diameter is also observed in the case of dispersion against the current (Figure 5 c, d),

where the value of chemically incomplete combustion at D_s = 0.7 mm in the plane R_2 decreases 5-6 times, and in the plane R_4 - 9-10 times.

The effect of the sprayer diameter on burning of the fuel jet can be explained basically by the quality of the dispersion of fuel and by the mixing processes. Indeed, according to the Sreznevskiy law, the burning time of the droplets of fuel is proportional to the square of the diameter [9]: $D_0^2 - D^2 = K\tau$, where D_0 and D = initial and running diameter of the drop, K = constant of the combustion

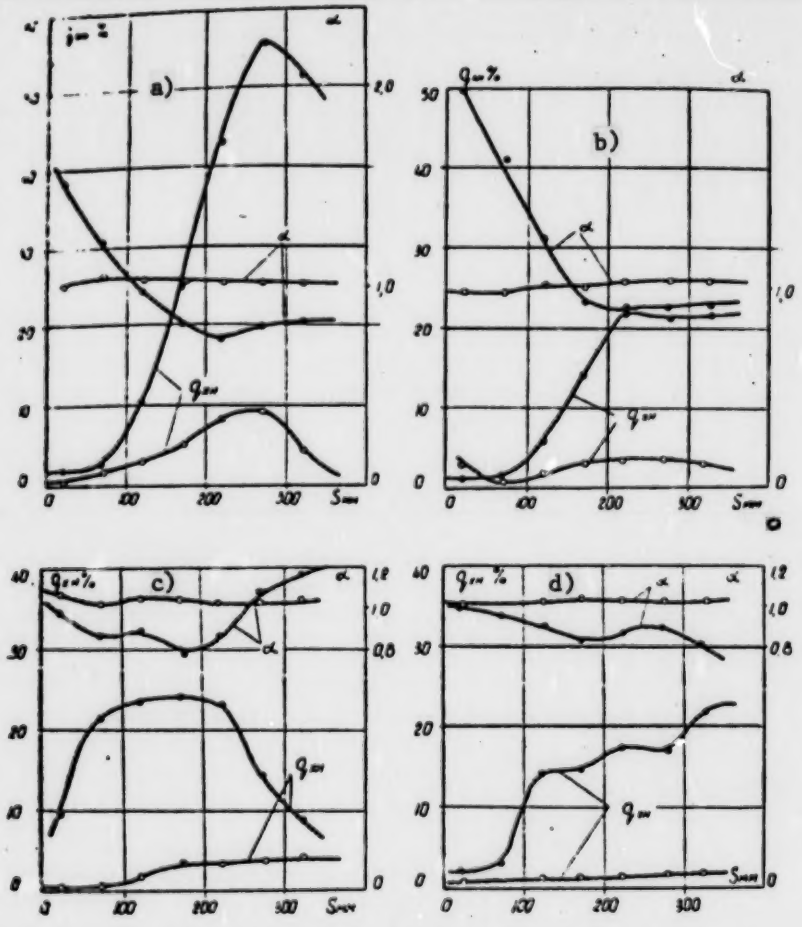

Figure 5. The effect of the output diameter of the sprayer on the chemically imcomplete combustion and on the coefficient of air excess: a and b - during dispersion with one sprayer of the diameter D_s 3 mm (denoted by —•—) and with 10 sprayers of the diameter D_s 0.7 mm (denoted by —o—), along the current; c and d - analogous to the above, but during dispersion against the current.

velocity, and τ = time. In the case of a coarse dispersion, the droplets burning time may increase 5-10 times, in comparison with a finely dispersed fuel.

On the other hand, the stream of hot air, moving at a high velocity - 120-170 m/sec — compresses the burning jet of fuel. In dispersion with one sprayer, the fuel does not mix sufficiently with the air, and enters the chamber in the form of a concentrated cluster with separate zones — impoverished ($\alpha \approx 2$) or excessively enriched with fuel ($\alpha \approx 0.75$). This feature delays considerably the process of combustion.

Effect of the spray direction. The arrangement of nozzles in such a way that the spraying of fuel is done against the current (of air) leads to a lowering of the chemically incomplete combustion (the maximum q_{XH}) by a factor of 1.5-2, in comparison with incomplete combustion for the reverse placement of sprayer nozzles.

When we have D_s = 3 mm, the dispersion of fuel against the current lowers the value of the maximum q_{XH} - in the plane R_2 from 56 to 25% (Figure 6 a), and in the plane R_4 - from 22 to 15% (Figure 6 b). The nonuniform distribution of the coefficient of air excess decreases — and it changes in the limits α = 0.75-1.2 along the radius R_2, and from 0.8 to 1.0 — along R_4.

With fine dispersion of fuel (D_s = 0.7 mm) the placement of the sprayers against the air current also proves to be beneficial, although the effect is smaller: the maximum chemically incomplete combustion decreases from 9 to 4% at R_2, and from 3.5 to 1.8% at R_4.

The effect of the sprayer arrangement on the chemically incomplete combustion can be explained, apparently, by the same reasons as the effect of the sprayer diameter. First, the spraying against the current increases the relative velocity between the air stream and the drops of fuel, which leads to an additional division of droplets. Secondly, the burning jet of fuel has a more spread out form, and the mixing of fuel with air improves.

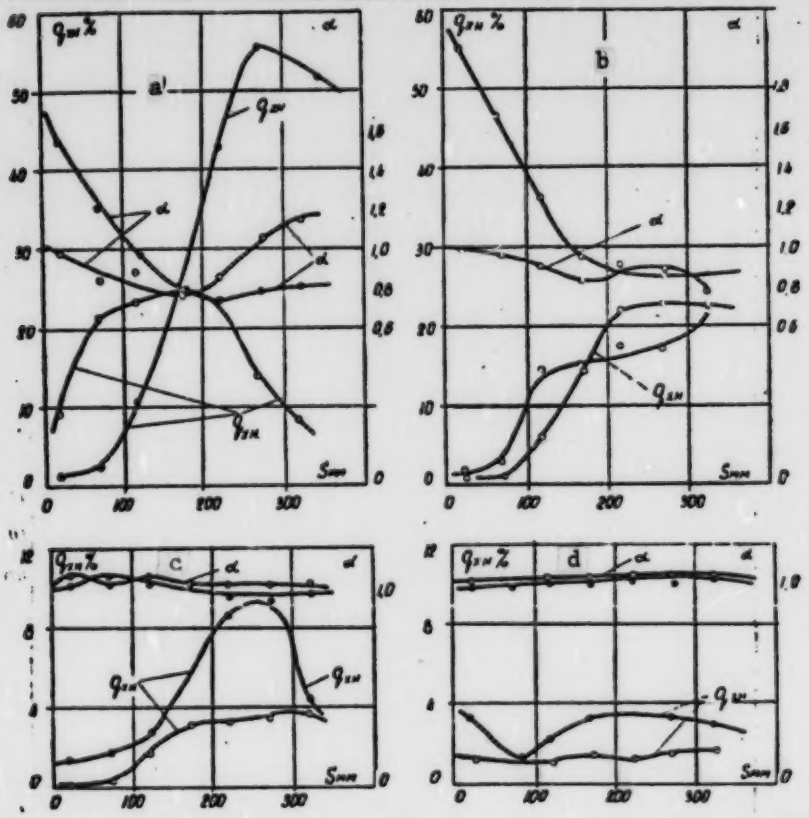

Figure 6. Effect of the direction of fuel spraying on the value of chemically incomplete combustion and on the coefficient of air excess: x — along the current; • — against the current; a and b — first sprayer with the exit diameter of 3 mm; c and d — 10 sprayers with exit diameter 0.7 mm, and uniform distribution along the transverse section of the inlet slit.

The effect of the fuel expenditure on the chemically incomplete combustion and on the coefficient of air excess proves to be less important, and also is connected with changes in the fineness of the spray. An increase in the fuel supply leads to a higher fuel pressure and lowers somewhat the size of the droplets. All this results in a corresponding decrease of the chemically incomplete combustion (10-15%).

The temperature field distribution. During an investigation of the effect of the fineness of liquid fuel dispersion on its combustion, detailed measurements were made of the temperature fields in the chamber. Use was made of a thermocouple PR 6/30, with the upper measurement limit of about 1800 °C.

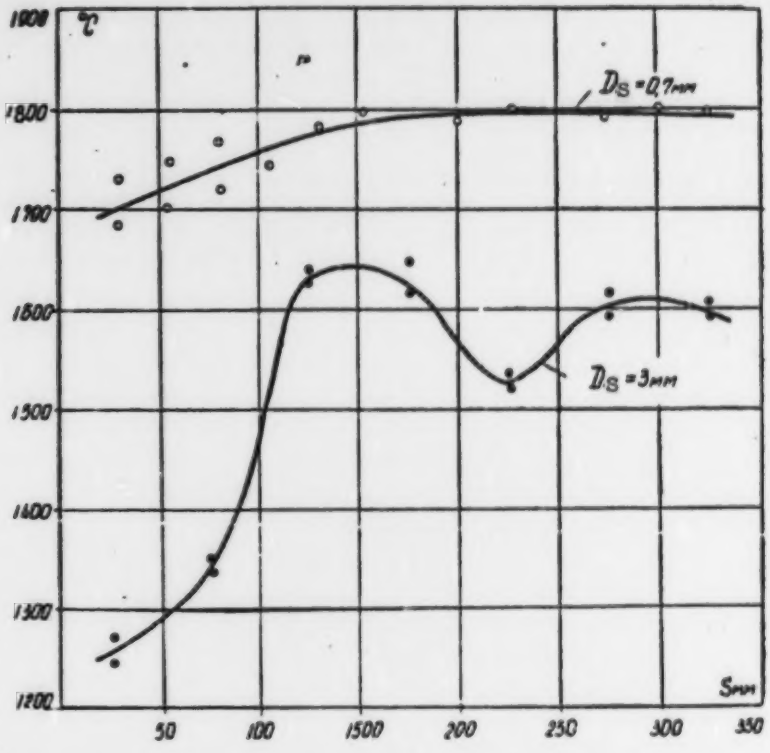

Figure 7. Effect of the sprayer nozzle exit diameter on the temperature distribution in an annular channel.

As an example, Figure 7 shows the temperature distribution along the depth of an annular channel during the dispersion of fuel with a sprayer diameter of 3 mm and a throughput of 220 kg/hour (the lower curve), and with a sprayer diameter of 0.7 mm and throughput of 150 kg/hour. We were unable to measure the temperature at a larger throughput and fine dispersion of fuel, since the weld of the thermocouple melted. It is necessary to note that the air preheating temperature with a sprayer diameter of 0.7 mm amounted to only 270 °C, as contrasted with 400 °C at D_s = 3 mm. It follows from the graph that with a fine dispersion of fuel the developed temperature is 150-450 °C higher than that with a coarse dispersion because of a

more extensive heat evolution (94-97%). This higher temperature is developed despite the fact that in the first case the fuel throughput is 30% smaller than in the second case. This is understandable, since the coefficient of heat evolution with coarse fuel dispersion is at a level of 45-50%, which results in a pronounced decrease of temperature. Also in this case, there are zones of a higher coefficient of air excess near the vent, α = 1.6-2.0, which also leads to a decrease of temperature.

We see thus that the fuel dispersion and its mixing with air exerts a significant influence on the conditions of fuel combustion in a cyclone chamber. With a coarse dispersion of fuel and its poor mixing with air, the process is not completed fully within the limits of the annular channel and even within the cyclone. But with a fine dispersion of fuel and its thorough mixing with air, it is possible to burn 95% of the fuel directly at a distance of 0.4-0.5 m from the inlet, and to complete 98.0-99.0% of the whole process of combustion in the annular channel. The potential of a chamber of this construction can be thus better utilized for processing technological raw materials.

Depending on the type of technological material, various schemes of burning the fuel in a cyclone are possible. For instance, during processing of material with a considerable content of carbon, which should be burned at the first stage of the process, it may be desirable to prolong intentionally the burning of the fuel jet. But, during the processing of an inert material, and in all other cases where it is necessary to complete the burning of liquid fuel at an input section, which is as short as possible, it is necessary, obviously, to employ a finely dispersed fuel injected directly into the secondary air, against the current, before its entrance into the cyclone.

Conclusions

1. The results of the investigations allow us to recommend with assurance this construction of the cyclone chamber with an upper outlet for gases and with a stabilizing annular channel for processing

finely granulated raw material. The stabilizing annular channel permits the burning of fuel directly in the top part of the chamber, and creation of a high and uniform level of temperature and complete heat evolution. Because of this feature, technological raw material can be stoked into the zone of sufficiently developed fuel stream combustion. Consequently, the ballast effect of the charge will not be to lower the intensity of the process, thus predetermining a high effectiveness of thermal treatment of the material.

2. A chamber of this construction possesses a high separational capacity because of the increased time solid particles of fuel and technological material remain in it. This increased time is due to the double circulation of the current in the annular channel. This feature is of particular importance for sublimation processes, where one of the basic technological indicators is the enrichment of sublimates with volatile metals.

3. When working with a liquid fuel, the highest heat evolution at the inlet part of the chamber is reached when the fuel is finely dispersed (with droplet radii less than 100 microns) and injected directly into the secondary air, against the current.

4. As a result of separation of the smelting products in the reaction volume, the cyclone chamber with an upper outlet for gases precludes the possibility of reverse reactions between the products, thus ensuring high technological indicators of the process.

5. One can assume that equipping such a cyclone chamber with the electrothermal device of oxygen-cyclone electrothermal equipment will prove to be more expedient than a chamber with a joint outlet for melt and gases.

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